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# APPLICATION DATA SHEET

Electronic Version v14

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| **Title of Invention** | Wavelength stabilization of semiconductor diode lasers using self-seeding photons |

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| Application Type : | provisional, utility |
| Attorney Docket Number : | IPS1000 |

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| TRANSMITTAL |
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Electronic Version v1.1

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| Title of Invention | Wavelength stabilization of semiconductor diode lasers using self-seeding photons |
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| Mr. John Charles Connolly | John C. Connolly | Inventor |

| Documents being submitted: | Files |
|---|---|
| us-fee-sheet | IPS1000-usfees.xml |
| | us-fee-sheet.xsl |
| | us-fee-sheet.dtd |
| us-request | IPS1000-usrequ.xml |
| | us-request.dtd |
| | us-request.xsl |
| application-body | IPS1000v5-trans.xml |
| | us-application-body.xsl |
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| | wipo.ent |
| | mathml2.dtd |
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| | IPS1000Fig3a.tif |
| **Comments** | |

Electronic Version
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# Description

# *Wavelength stabilization of semiconductor diode lasers using self-seeding photons*

## BACKGROUND OF INVENTION

[0001] Summary of the Related Art:

[0002] Typical semiconductor laser diodes are formed by a body of semiconductor material having a thin, active region formed between cladding layers and contact regions of opposite polarity. A longitudinal waveguide is formed in the structure by defining a stripe for light guiding and for current injection. Light is generated in the active region when the stripe region or the laterally confined waveguide region is subject to current flow between the positive and negative contact regions. Cladding and confinement regions, among others, are placed between the contacts and the active region for guiding and confining the light along the thickness of the layers. The various regions typically

are formed as substantially parallel thin layers grown epitaxially using techniques such as metalorganic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE) or other growth technology known in the field.

[0003] Discrete devices are defined in the lateral direction or in the direction along the active region using oxide-defined contact stripes, lateral index profile regions or other techniques to define a lasing region whose width is determined by the need of the specific application. These widths for discrete elements can vary from about three to about five hundred microns depending on the application. In a bar format containing a plurality of elements, the lateral width and the number of discrete elements along the bar are dictated by both the application and the thermal management requirements. A common term use to define the extent of the plurality of laser elements is the fill factor. The fill factor can be defined as the ratio between the lasing or light emitting width over the total semiconductor width. A typical bar width is a 1-cm while the majority of fill factors in use range from about 20% to 75% but could be as low as 10% and as high as 90% for some applications. The fill factor is also strongly dependent on the output power in either pulsed or CW operation mode

where the former leads to higher fill factors and the later to lower fill factors.

[0004] The active regions can be comprised of one or more quantum wells (QWs) having a specified thickness, length and width. Light generated and supported by the laser structure is restricted to specific modes in both the lateral and longitudinal directions. The longitudinal modes are dictated by the length of the laser cavity, and characterized by each having its own operating frequency or wavelength. In the lateral direction, on the other hand, the mode profiles are determined by the width and material composition (i.e. refractive index of the cross section). Each of these modes is characterized by its lateral mode profile and effective index. Similarly, the thicknesses and refractive indices of the various layers restricts the oscillation of the light waves in the transverse direction or the direction perpendicular to the plane of the layers along which light propagates. By appropriately designing the thickness and material composition of the various layer(s), as well as the cross section profile, oscillations can be restricted to the fundamental light mode or to other desired modes of oscillation. It should be noted that in the lateral direction, where modes are limited by the width of the

stripe and of the current flow region, more than one mode could co-exist simultaneously within the active layer.

[0005] One problem encountered in this type of semiconductor laser diode is that the light emitted may consist of more than one optical mode in the lateral direction, as described above. Further, changing operating conditions, such as the drive current, the operating temperature, etc. along with the non-linear effects within the laser cavity results in lateral mode hoping and gain competition. This, in turn, would adversely affect the spectrum and linewidth of the laser. While many applications require laser light that has a far field pattern consisting of a plurality of spatial modes, these same applications require a specific defined spectrum (i.e. frequency and linewidth consisting of one or more longitudinal modes).

[0006] Accordingly, there is a need for controlling the longitudinal mode frequency as well as the linewidth of the mode. Further, by defining and stabilizing the peak wavelength using self-seeding photons, an increase device yield for both a given wafer and from wafer to wafer is obtained since the entire gain bandwidth of the device can be utilized. By carefully tailoring the linewidth of the self-seeding mechanism to the element, the exact number of

modes or even a single mode can be selected for lasing. This provides enormous flexibility in the overall design and permits application specific frequency tailoring.

## SUMMARY OF INVENTION

[0007] The present invention is directed to single and multi-lateral-mode semiconductor laser diodes and lasers arrays, and a related method that is adapted to control the longitudinal modes of the laser light generated, so that only desired modes are supported. In particular, this result is achieved by controlling the frequency and number of photons that are selectively fed back into the lasing cavity. We call this process self-seeding since the light or photons used for stabilization are a fraction of the initial light generated by the laser source. Stabilization can be established using only a small percentage of the total photons available. The number of photons required is dependent upon optical losses in the system, facet reflectivity, available gain, and wavelength stabilization element (WSE) reflectivity. This process eliminates the need for a separate frequency stabilized light source that is commonly used for laser frequency stabilization by injection locking. The methodology can be applied across all material systems as well as all semiconductor diode laser sources for both

discrete elements and laser arrays. It is also suitable for all lateral device widths independent of the form of the lateral mode control. Thus, the lateral dimensions of the high gain active layer can be selected to support a desired number of modes of the laser light, such as the fundamental mode or a combination of the fundamental and higher order modes. A schematic diagram illustrating the technology is shown in Figs. 1a and 1b for single-mode and multi-mode semiconductor laser technology, respectively.

[0008] The lateral mode control of the active layer region could be achieved by a number of methods known in the art, such as the use of oxide-masking to define the current contact stripe openings, the use of ridge waveguide formation to selectively change the lateral index step for optical mode confinement, lateral mode confinement using a buried heterostructure configuration, or implanting high energy ions, such as protons, in portions of the active layer to reduce the current conductivity in these areas, while shielding portions of the active layer where high gain, and therefore high conductivity, is desired. To achieve these and other advantages and in accordance with the purpose of the invention as embodied and

broadly described, in one aspect the invention is a single or multi-spatial-mode semiconductor laser diode or an array containing a plurality of discrete elements, and a wavelength selective reflector whose bandwidth and reflectivity are tailored such that a single longitudinal mode or a plurality of longitudinal modes is be selected for lasing.

[0009] The process of selected feedback can be accomplished using a one or more of the technologies discussed below. The key is to provide only the selected frequencies of interest. One such technology for feedback and self-seeding of the laser is by using a dielectric coating in conjunction with selected optical feedback. A narrow frequency selective filter can be created using a series of $\lambda/4$ layers on a glass surface and then coating a reflective film on the opposite side of the glass. A wedge piece of glass would be most suitable since the desire frequency can be easily selected. The results of implementing this approach using a very low reflection coating on a visible laser source before and after the insertion of the WSE is shown in Fig. 2. The total number of $\lambda/4$ layers in the dielectric film determines the frequency window for optical feedback. For the case displayed here, the number of $\lambda/4$ lay-

ers used was about thirteen. Increasing the number of layers would narrow the linewidth or bandpass of the WSE while reducing the number would broaden it. For the device data shown here the output emission was reduced from a free-running state of ~ 8-9 nm to a self-fed photon state of ~ 2 nm. As mentioned previously decreasing the bandwidth of the filter would also decrease the output emission to values below 0.1 nm. Thus the output emission or linewidth of the laser is dependence upon two key parameters the bandpass window of the filter and the reflectivity of the filter at the lasing wavelength. Filter loss also must be considered when designing the light source.

[0010] Other technologies well known in the art to construct efficient narrow band reflectors are grating-based technologies such as volume phase gratings (VPGs), volume Bragg gratings (VBGs) and volume phase hologram-based filters (VPHF). These technologies use photosensitive glass that provides an optical waveguide with periodic variations in the refractive index for producing frequency selective mirrors. In fact, any technology that can provide frequency selective reflectivity can be utilized to construct a WSE and be used for self-seeding frequency selective and stable lasers. Fig. 3 is a schematic diagram of a "C-Block"

mounted laser with a lens and a WSE positioned in front of the emitting facet to provide photon self-seeding for wavelength stabilization.

## BRIEF DESCRIPTION OF DRAWINGS

[0011] The accompanying drawings are included to provide further understanding of the invention, and are incorporated in and constitute a part of the specification, illustrating embodiments of the invention and, together with the description, serve to explain the objectives, advantages and principles of the invention.

[0012] Figure 1a and 1b are schematic diagrams showing detail of two embodiments for single-mode and multi-mode semiconductor diodes with the WSE in place for frequency selectivity and wavelength stabilization.

[0013] Figure 2a is a free running spectrum from a 785 nm broad-stripe semiconductor laser. The linewidth of the spectrum is about 8-9 nm at the full width half maximum (FWHM) value. Figure 2b is the spectrum of the same laser with the WSE element inserted in the optical path. The WSE element is a narrow bandpass filter with a partial reflector to supply a small portion of photons back into the cavity for self-seeding. The linewidth of the spectrum is reduced to about 2 nm at the full width half maximum (FWHM)

value and is center at about 785 nm.

[0014] Fig. 3. Schematic diagram of the C-Block with collimating lens and wavelength stabilization element (WSE).

## DETAILED DESCRIPTION

[0015] Detailed Description of the Preferred Embodiments of the Invention

[0016] Semiconductor laser diodes are used in a variety of applications such as optical data storage and compact disc drives, for printing processes such as those used in laser printers, for optical pumps in solid-state lasers, and as light sources in test and instrumentation equipment. For certain applications, where higher optical power is required, a plurality of laser diodes can be assembled in arrays, such that the emitted light is contributed by all of the arrayed laser diodes. In this case the laser array is said to share the same lateral mode and in some cases are also phase-locked.

[0017] For many applications is it desirable to control the peak frequency, peak power as well as the linewidth of the light source. In conventional laser diodes the emission spectra, peak power levels, and linewidths are independent of one another such that these parameters varied widely from one device to the next. Thus for many applications these

parameter variations must be accounted for with additional electronics and temperature control such that each system must be carefully adjusted to achieve a light sources that have a common set of operating parameters. Further minor changes internal to the diode laser during operation must be accounted for by control circuitry. Thus the ability to eliminate the individual control circuitry for each laser is paramount to achieving product acceptable in the commercial marketplace.

[0018] Another desirable operating feature for multi-mode diode lasers is the ability to reduce their linewidth and stabilize the number of longitudinal modes. Incorporating a WSE into the optical path to pre-select the lasing mode facilitates a fixed and stable frequency source having a fixed linewidth. Moreover, all laser light sources coupled to the WSE would operate at the same frequency and with a similar number of longitudinal modes.

[0019] It will be apparent to those skilled in the art that various modifications and variations can be made in the application of the WSE to the laser diode and the methodology of the present invention, without departing from the spirit or scope of the invention. One of these modifications would include the WSE elements as the emitting facet in an ex-

ternal cavity laser configuration. In this embodiment the optical coating applied to the output facet is reduced to a level where the feedback for lasing is primary provided by WSE. This particular approach leads to narrower linewidths and improvement to the wavelength stability both with increased operating temperature and operational time.

Thus, the present invention is intended to encompass the modifications and variations that come within the scope of the appended claims and their equivalents.

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# Claims

[c1]

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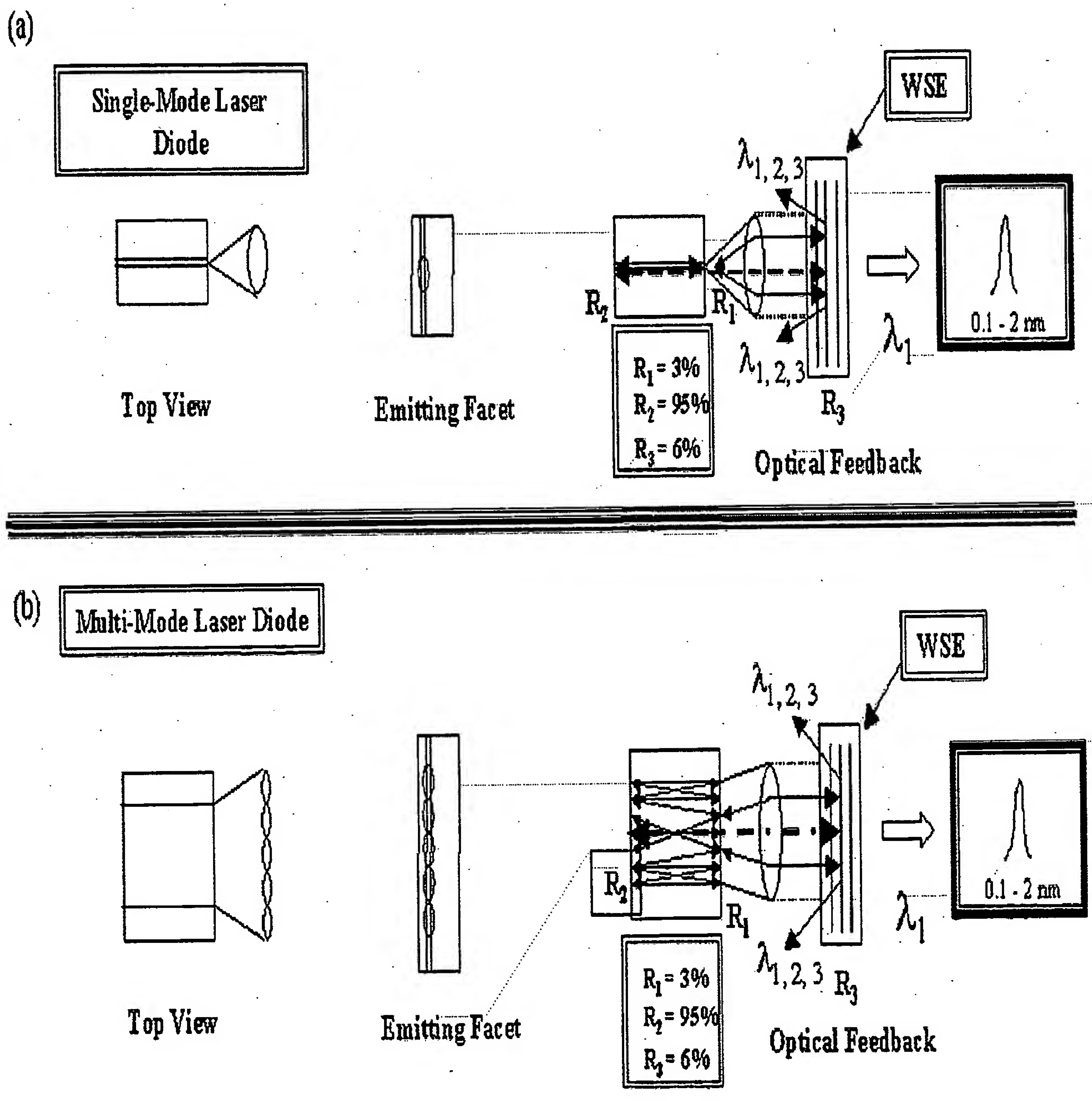
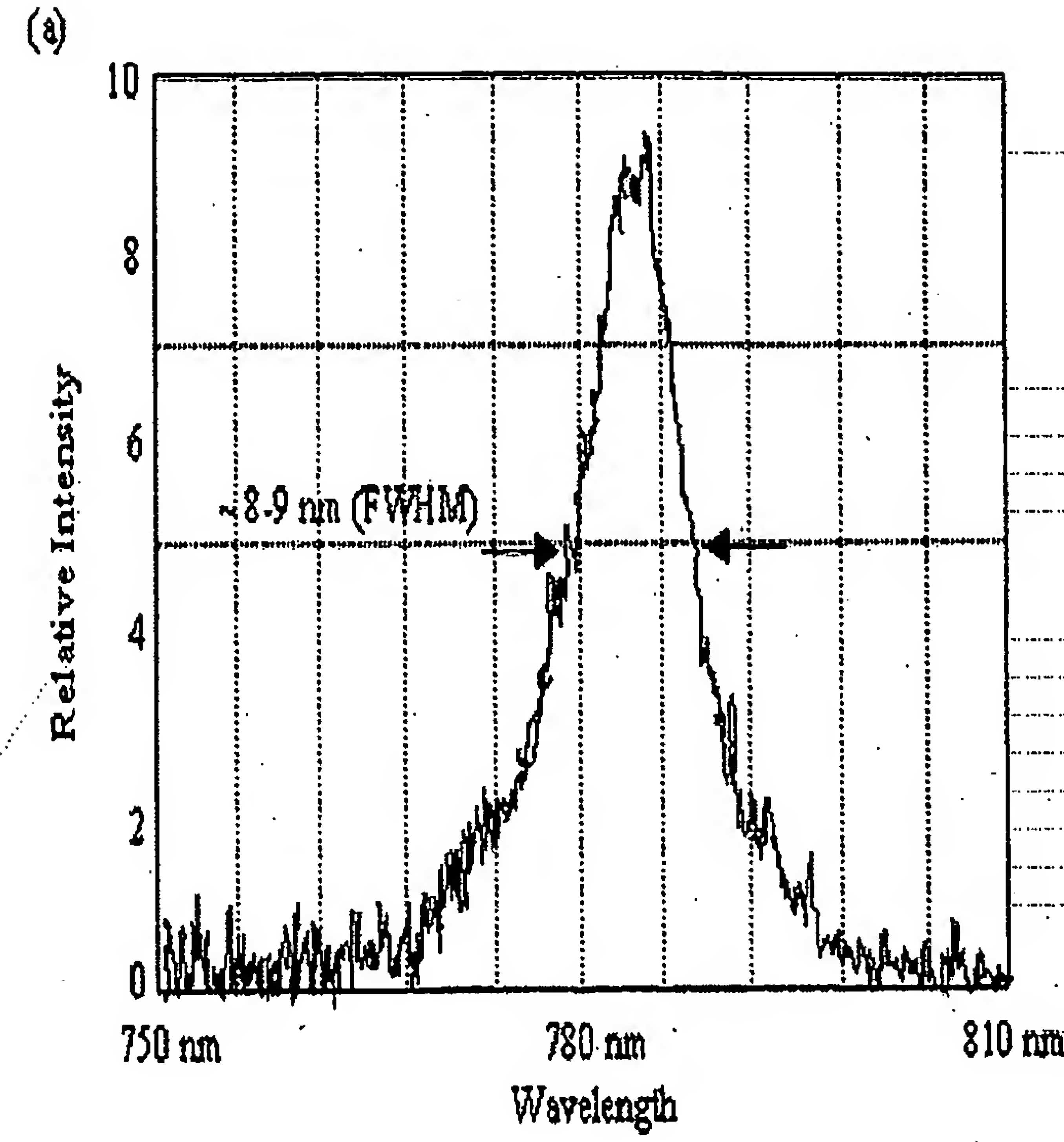
# *Wavelength stabilization of semiconductor diode lasers using self-seeding photons*

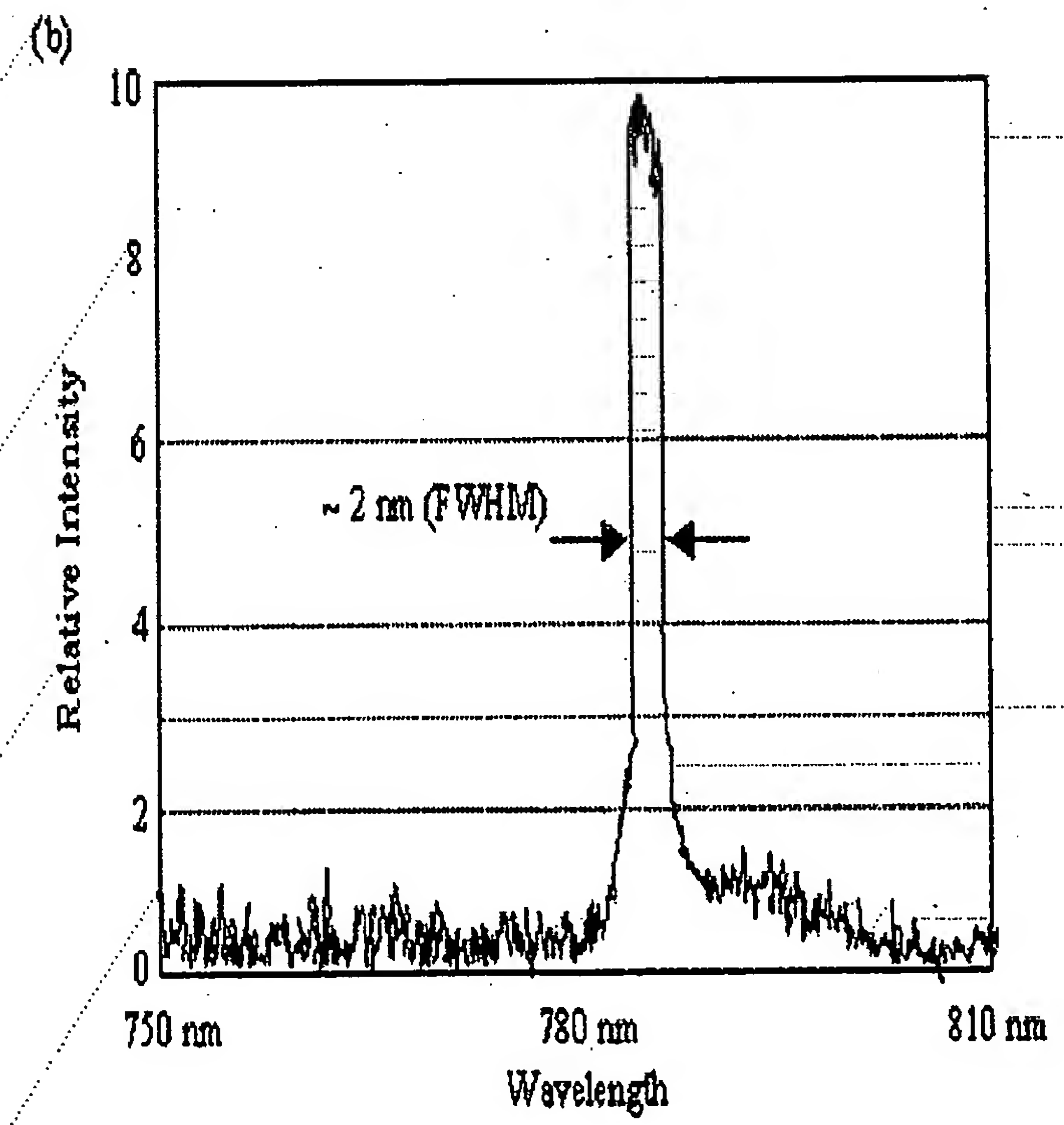
## Abstract

The present invention relates to controlling the frequency and linewidth of discrete narrow- and broad-stripe semiconductor lasers and laser bars for applications requiring high output power with stabilized and/or selected linewidth such as optically pumping solid-state lasers, Raman spectroscopy, sensing applications, etc. The use of a self-seeding technique stabilizes the longitudinal modes in both narrow and broad stripe lasers and provides an extra benefit of temperature and power stabilization in discrete elements, as well as in 1 and 2 dimension bar formats.

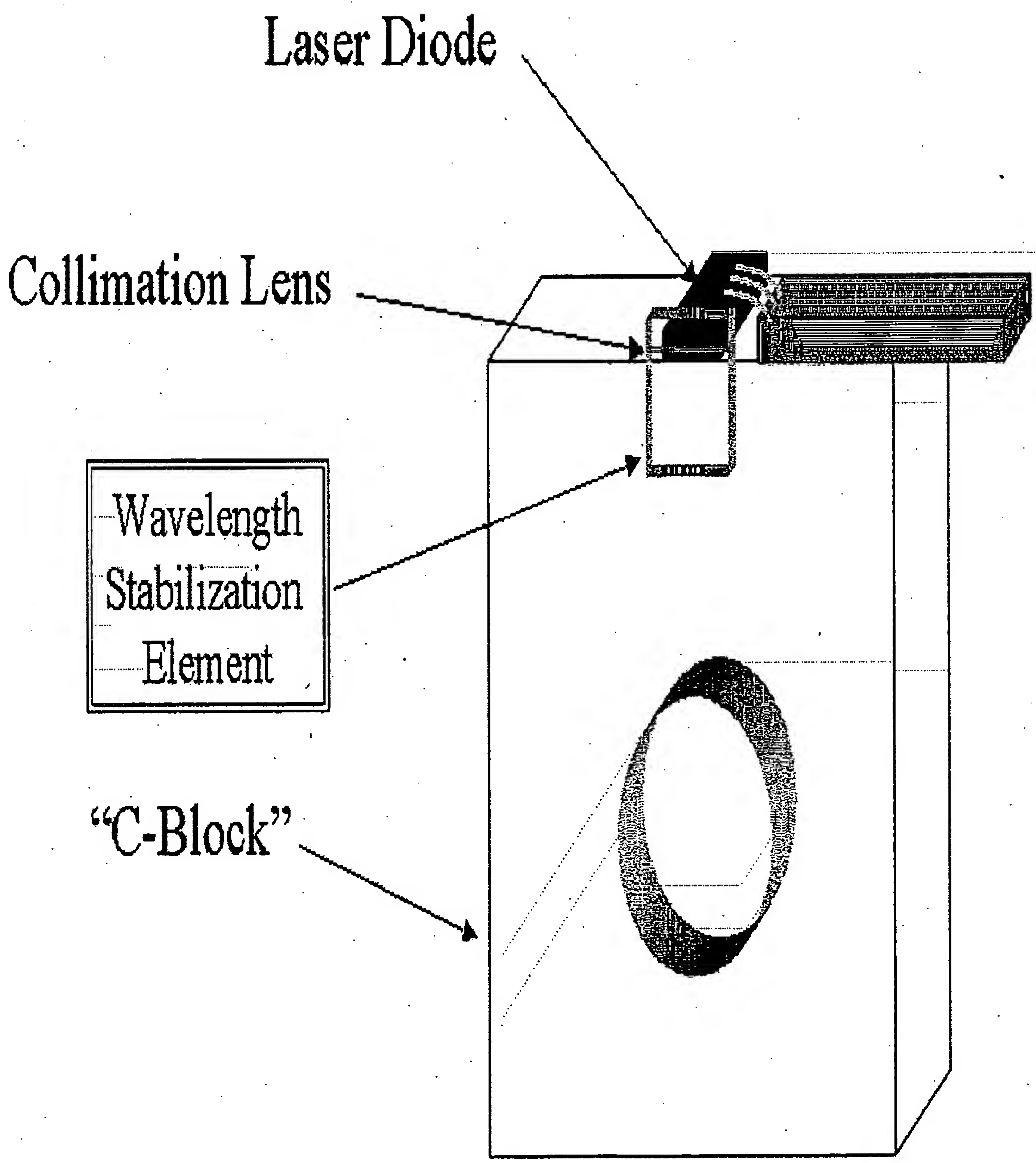



IPS 1000 – Figure 1




IPS 1000 – Figure 2




IPS 1000 – Figure 3